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PARAMETRIC STUDY OF POTENTIAL EARLY COMMERCIAL POWER PLANTS TASK III-A MHD COST ANALYSIS

FINAL TECHNICAL REPORT

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GENERAL ELECTRIC COMPANY

ADVANCED ENERGY PROGRAMS DEPARTMENT

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SECTION 1

INTRODUCTION

The overall goals of the program are the development of costs for an MHD Power Plant and the comparison of these costs to a conventional coal fired power plant. The program is subdivided into three basic activities:

Activity 1 - Code of Accounts Review

Activity 2 - MHD/Pulverized Coal Power Plant Cost Comparison

Activity 3 - Operating and Maintenance Cost Estimates

The objective of Activity 1 was to define the scope of each NASA code of account item and to assure that the recently completed Task III capital cost estimates are consistent with the code of account scope. Each major item within the scope of the NASA code of accounts category was identified using a detailed code of account system for conventional pulverized coal fired power plants. A listing of these items per account category was prepared and reviewed with NASA personnel to assure that the listing was complete and that there were no overlapping entires.

Utlizing this agreed-upon listing, General Electric and Bechtel then reviewed the MHD plant capital cost estimates prepared under Task III, and made modifications as necessary to reconcile these estimates with the lists.

The objective of Activity 2 was to improve confidence in MHD plant capital cost estimates by identifying comparability with conventional pulverized coal fired (PCF) power plant systems.

The MHD power plant design was broken down to systems and sybsystems with functions, scope and criteria similar to systems in conventional pulverized coal power plants. System capacities required for MHD plants with overall rating comparable to the pulverized coal power plant were defined. Where comparability with pulverized coal power plants could not be ascertained, the systems were further broken down to component level to seek comparison with commercially available items of comparable rating. The capital cost of the MHD systems and components were then estimated by comparing with similarly rated systems and components in pulverized coal fired power plants. General Electric and Bechtel in-house data and, as needed, vendor quotations were used to develop these estimates. Bulk factors were estimated by comparing technical scopes of systems and components. General Electric with Bechtel, in an iterative review process, defined the boundaries of MHD and

balance of plant systems to ascertain that items were neither omitted or duplicated.

The objective of Activity 3 was to verify the basis for estimating the MHD plant operating and maintenance costs and the cost of electricity as previously defined in Task III.

The staffing requirements for the operation and maintenance of MHD plants were reviewed in comparison with that of conventional pulverized coal fired power plants. As applicable, this comparison was based on the system breakdown defined in Activity 2. The fixed component of the O&M cost was based on the cost of labor for the staff, the capital charges and fixed maintenance material costs. The variable component of the O&M cost includes the cost of consumable chemicals and waste disposal. A first year and a 30 year levelized figure for O&M costs and for the cost of electricity was calculated.

SECTION II

TECHNICAL SUMMARY

Activity 1 - Code of Accounts Review

A scope list for the NASA Code of Accounts was compiled and is included in this report as Appendix A. This list is based on the "Economic Ground Rules and Cost Estimate Reporting Guidelines" supplied by NASA, MHD Component Account Codes supplied by General Electric and by Bechtel's in-house Code of Accounts for the balance of plant items. The scope list was utilized to define system boundaries for cost estimating purposes and to insure that items were neither omitted nor duplicated.

Estimates presented in this study use existing cost data and historical cost reports available to Bechtel, supplemented by inputs from General Electric and DOE/NASA for the specific MHD equipment and materials. The existing data and estimates are appropriately modified to reflect differences in size and type of facilities. Estimates also reflect judgments made on the basis of analyses of historical cost reports.

Capital cost estimates of the conventional facilities of the MHD plant have been developed by comparison and reconciliation with historical costs of similar facilities for pulverized coal fired (PCF) plants.

The cost estimate for the PCF plant actually used for the comparison was published in an Electric Power Research Institute (EPRI) Report No. PE-1865, Coal-Fired Power Plant Capital Cost Estimates, May 1981. This report, prepared by Bechtel Power Corporation, includes capital cost estimates for fifteen plants at various locations and burning various coals. The fifteen estimates are also compared with the actual published costs from industry sources for approximately 140 individual coal-fired units. This comparison shows that the range of estimated costs are moderately higher than the mean of the published data, indicating the conservatism of the cost estimates.

The estimate for Plant #2 in the EPRI report has been selected as the most appropriate for comparison to the MHD plant estimate. This plant, located in mid-America, fulfills the MHD plant estimate requirements better than any of the other

plants. The estimate has the same productivity level and wage rates as used in previous MHD estimates. The plant is fired with sub-bituminous western coal and has design and building service features appropriate for the location.

The new estimate for the 1100 MWe MHD power plant developed through this study is presented in Table 1. The estimate is in the NASA format. Total cost including interest during construction and escalation (IDC & E) is $866.4 million at mid-1978 price level. This includes the costs of land and land rights - 450 acres @ $5,000 per acre. Land area includes approximately 300 acres for the solid waste disposal for 30 years.

Direct costs (the first three columns in Table 1) and indirect costs reflect Bechtel's conventional PCF plant experience as shown by the comparisons in Activity 2. Contingency is 20% on the MHD accounts 317.1 through 317.4 and 15% on all other accounts as appropriate for this conceptual level estimate. Architect engineering services and IDC&E costs are included at the same percentage as used in previous MHD estimates, reflecting a project duration of six years.

Table 1

1100 MWe MHD PLANT COST ESTIMATE

(Mid-1978 $ Millions)

Acct. No.	Account Description	Matl. Cost Maj. Comp.	Matl. Cost BOA	Installation Cost	Indir. Cost	Cont.	Total
310.0	Land and Land Rights	--	2.3	--	--	0.3	2.6
311.1	Improvements to Site	--	3.0	15.3	1.9	3.0	23.2
311.2	Main Buildings	--	14.8	9.2	2.5	4.0	30.5
311.3	Steam Turbine Bldg.	--	5.3	3.3	0.9	1.4	10.9
311.4	Coal Bunker/Process Area	--	5.5	3.5	0.9	1.5	11.4
311.5	Service Buildings	--	2.4	1.6	0.4	0.7	5.1
311.6	Other Process Bldgs.	--	7.8	4.9	1.4	2.1	16.2
312.1	Coal Hndl. & Proc.	19.5	6.6	1.5	2.9	4.6	35.1
312.2	Slag and Ash Handling	--	4.7	0.7	0.6	0.9	6.9
312.3	Radiant Sections	**					
312.4	Stm. Gen. Sections	35.6	--	11.7	5.0	7.8	60.1
312.5	Effluent Control	14.9	1.3	0.9	1.8	2.8	21.7
312.6	Auxiliary Boiler Sys.	--	0.4	0.1	0.1	0.1	0.7
312.7	Other Boiler Plt. Sys.	--	8.4	1.9	1.1	1.7	13.1
314.1	Stm. Turbine Gen. & Aux.	30.2	--	1.1	3.3	5.2	39.8
314.2	Condenser & Aux.	--	1.7	0.3	0.3	0.3	2.6
314.3	Circ. Water System & CT	--	5.0	1.1	0.6	1.0	7.7
314.4	Steam Piping Sys.	--	4.9	3.0	0.8	1.3	10.0
314.5	Other Turbine Plant Equip.	--	3.3	0.4	0.4	0.6	4.7
315.0	Acc. Elec. Sys. & Equip.	--	24.9	26.6	5.4	8.5	65.4
316.0	Misc. Power Plant Equip.	--	12.7	8.1	2.2	3.5	26.5
317.1	Combustion Equip.	13.8	--	3.3	1.8	3.8	22.7
317.2	MHD Gen. System	11.3	--	0.3	1.2	2.6	15.4
317.3	Magnet System	58.3+	--	--	6.1	12.9	77.3
317.4	Inv. & Elect. Cnt. Sys.	39.0	--	5.5	4.7	9.8	59.0
317.5	Oxidizer System	14.2	4.6	5.2	2.5	4.0	30.5
317.6	Seed System	8.7	2.0	5.1	1.6	2.6	20.0
317.7	Oxygen Enrichment Sys.	52.3	11.9	9.5	2.4	11.4	87.5*
317.8	Misc. MHD Top Cycle Eq.	--	4.3	0.4	0.5	0.8	6.0
350.1	Main Transformers	--	3.7	0.1	0.4	0.6	4.8
350.2	Switchyard	--	9.7	2.4	1.3	2.0	15.4
	Subtotals	297.8	151.2	127.0	55.0	101.8	732.8
	A/E Eng'n Services						59.7
	Total Overnight Const. Cost						792.5
	IDC&E						73.9
	Total Cost Incl. IDC&E						866.4

* Includes A/E Eng'n Services and IDC & Escalation
\+ Includes Installation
** Included in 312.4
BOA = Balance of Account

Activity 2 - MHD/Pulverized Coal Power Plant Cost Comparison

Table 2 provides a comparison of the MHD estimate and the PCF Plant # 2' from the EPRI report. Estimate comparisons are by functional categories and expressed as percentages of total mechanical equipment costs. These percentages measure the level of services and plant features such as buildings,piping, electrical, controls, site development, etc., provided for the mechanical equipment. The similar percentages for these functional categories indicate that both plants have a similar level of services and features. Since the percentages for the PCF plant #2 estimate reflect actual and conservative design of PCF plant services, the similar percentages are believed to reflect the same conservatism for the MHD plant facilities.

Additional comparisons of the MHD and the PCF plant estimates are given in Table 3 with annotations in Table 3A. Table 3 provides line by line comparisons in the NASA code of accounts. One column is shown for the MHD estimate. Three columns are shown under the PCF estimates. Comparisons are between the MHD column and the column, "Adjusted for MHD Plant Component Size". The latter column was developed from the other two PCF estimate columns. From left to right, the first PCF column is the Plant #2 estimate for two 500 MW_e units as given in the EPRI report, recast in the NASA Code of Accounts and with a total overnight construction cost of $726.5 million. This is $724.5 million + $2.0 million for land. The second column is adjusted to be the estimate for only 1 x 500 MW_e unit. From this column, the third or comparison column is developed by scaling the cost of the PCF plant component for the size appropriate for the 1100 MWe MHD plant. The table shows:

- $273.9 million out of $576.0 million or approximately 47% of the total MHD estimate is supported by historical cost data through comparison and reconciliation with the PCF estimate.
- An additional 20% of the estimate, Accounts 317.5 through 317.8, is for proven technology items - oxygen plant, compressors and drivers, etc., - whose costs are based on historical data.
- The remaining 33% of the estimate covers first-of-a-kind equipment in the sizes and capacities required.

Table 2

MHD AND PCF POWER PLANT
COST ESTIMATE COMPARISONS
(Mid-1978 $ Millions)

Description	2 x 500 MWe PCF Plant		1 x 1100 MWe MHD Plant	
	$	% of Mech	$	% of Mech
Land	$ 2.0	0.6%	$ 2.3	0.7%
Mechanical	313.1	100.0	324.3	100.0
Inverter	--	--	44.5	13.7
Electrical	38.5	12.3	42.9	13.2
Piping	49.1	15.7	47.8	14.7
Control & Instr.	13.7	4.4	12.4	3.8
Inverter Bldg.	--	--	3.7	1.1
Fdns. & Bldgs.	64.7	20.6	67.7	20.9
Piles & Caissons	10.3	3.3	--	--
Site & Earthwork	17.2	5.5	18.3	5.6
Site Specific Earthwork	9.9	3.2	--	--
Switchyard	11.4	3.6	12.1	3.7
Direct Cost	$529.9		$576.0	
Indirect Costs	54.1		55.0	
Total Field Cost	584.0		631.0	
Contingency	86.7		101.8	
Subtotal	670.7		732.8	
A/E Services	55.8		59.7	
Total Overnight Const. Cost	$726.5		$792.5	

Table 3

MHD/PCF PLANT COST COMPARISON ON A
COMMON SYSTEMS/COMPONENTS BASIS
(Mid-1978 $ Millions)

Account No.	Account Description	MHD Plant 1x1100 MWe	PCF Plant 2x500 MWe	PCF Plant Adj. for 1x500 MWe	PCF Plant Adj. for 1100 MWe MHD Plant Component Size
310.0	Land and Land Rights	$ 2.3	$ 2.0	$ 1.6	$ 2.3
311.1	Improvements to Site and Earthwork	18.3	17.2	9.3	19.8
	Site Specific Earthwork	-	9.9	5.3	-
	Piles	-	10.3	5.6	-
311.2	Main Buildings				
.21	MHD	13.8	-	-	-
.22	Steam Generator				
	Foundations	1.7	2.5	1.2	1.7
	Building Enclosure	*	4.6	2.0	-
	Coal Preparation	**	2.0	1.0	-
.23	Effluent Control				
	Electrostatic Precipitator	0.7	1.0	0.5	0.7
	Ash Handling Facilities	***	6.5	3.5	-
	FGD Facility	-	5.1	2.6	-
.24	Inverter	3.7	-	-	-
.25	Control	4.1	3.2	3.2	4.3
311.3	Steam Turbine Bldg.	8.6	14.9	8.0	8.2
311.4	Coal Bunker/Process Area	9.0	12.8	6.9	8.9
311.5	Service Buildings				
.51	Service	2.8	3.2	3.2	3.2
.52	Administration	1.2	2.1	2.1	2.1
311.6	Other Process Buildings				
.611	Air Compressor	****	-	-	-
.612	Air Separation	****	-	-	-
.613	Oxygen Compression	****	-	-	-
.614	Nitrogen Compression	****	-	-	-
.62	Circ. Water Pump House	1.3			
.63	Water Treatment	3.3			
.64	Fuel Oil Storage	0.1	5.8	3.6	4.4
.65	River Intake Structure	0.1			
.66	Seed Reprocessing & Storage	4.7	-	-	-
.67	Seed Injection	2.4	-	-	-
.68	Cooling Tower Basin	0.5	1.0	0.5	0.7
.69	Inverter Area Foundations	0.3	-	-	-
312.1	Coal Handling & Processing				
.11	Coal Rec. & Handle	7.6	7.9	4.7	7.1
.12	Coal Prep. & Feed	20.0	*		
312.2	Slag and Ash Handling	5.4	4.9	2.6	4.5

* Included in 312.4
** Included in 312.12
*** Included in 311.21 and 317.6
****Included in 317.7

Table 3 (Cont'd)

MHD/PCF PLANT COST COMPARISON ON A
COMMON SYSTEMS/COMPONENTS BASIS
(Mid-1978 $ Millions)

Account No.	Account Description	MHD Plant 1x1100 MWe	PCF Plant 2x500 MWe	PCF Plant Adj. for 1x500 MWe	PCF Plant Adj. for 1100 MWe MHD Plant Component Size
312.3	Radiant Sections	*	-	-	-
312.4	Stm. Gen. Sections	47.3	114.4	61.8	57.1
312.5	Effluent Control				
	Electrostatic Precipitator	14.9	50.1	27.0	25.0
	Stack	2.2	5.1	2.6	2.4
	FGD Process Facility	-	49.5	26.1	-
312.6	Auxiliary Boiler Systems	0.5	0.6	0.3	0.4
312.7	Other Boiler Plant Systems	10.3	17.2	9.3	10.0
314.1	Stm. Turbine Gen. & Aux.	31.3	55.2	29.8	30.5
314.2	Condenser & Aux.	2.0	4.7	2.3	2.3
314.3	Circ. Water System & CT	6.1	8.6	4.6	5.7
314.4	Steam Piping Sys.	7.9	10.6	5.7	7.5
314.5	Other Turbine Plant Equip.	3.7	7.3	3.8	3.9
315.0	Acc. Elec. Sys. & Equip.				
	Control System MHD Portion	4.8	-	-	-
	Electrical Equip. & Bulks MHD	20.3	-	-	-
	Control System PCF Portion	7.7	11.6	6.3	7.9
	Electrical Equip. & Bulks PCF	18.7	30.3	16.4	16.7
316.0	Misc. Power Plant Equip.				
	Other Mech Equip.	6.2	9.7	5.2	6.1
	Piping	14.6	23.0	12.4	14.6
317.1	Combustion Equipment				
	Primary Gasifier	5.1	-	-	-
	Slag Receiver	1.4	-	-	-
	Second Stage Combuster	1.2	-	-	-
	Slag Quench Tank & Ducts	1.8	-	-	-
	Auxiliary Components	7.6	-	-	-
317.2	MHD Gen. System				
	Nozzle	0.3	-	-	-
	MHD Generator	10.0	-	-	-
	Diffuser	1.3	-	-	-
317.3	Magnet System				
	Magnet	41.8	-	-	-
	Cryogenic Subsystem	3.8	-	-	-
	Misc. Materials	3.7	-	-	-
	Assemble & Install	7.0	-	-	-
	Inst. & Control	2.0	-	-	-

*Included in 312.4

Table 3 (Cont'd)

MHD/PCF PLANT COST COMPARISON ON A COMMON SYSTEMS/COMPONENTS BASIS (Mid-1978 $ Millions)

Account No.	Account Description	MHD Plant 1x1100 MWe	PCF Plant 2x500 MWe	PCF Plant Adj. for 1x500 MWe	PCF Plant Adj. for 1100 MWe MHD Plant Component Size
317.4	Inv. & Elect. Control System				
	Inverters	11.6	-	-	-
	Current Consol. Equip.	3.9	-	-	-
	Inst. & Controls	6.4	-	-	-
	D. C. Reactors	3.8	-	-	-
	A. C. Filters	3.2	-	-	-
	Transformers	9.8	-	-	-
	Switchgear & D. C. Breakers	5.8	-	-	-
317.5	Oxidizer System				
	Main Compressor & Driver	$ 12.8	-	-	-
	Condenser	1.4	-	-	-
	Piping	9.8	-	-	-
317.6	Seed System				
	Seed Handling	0.6	-	-	-
	Seed Injection	1.8	-	-	-
	Formate Plant	10.4	-	-	-
	Formate Plant Piping	3.0	-	-	-
317.7	Oxygen Enrichment System	73.7			
	Air Compressors & Drivers,	-	-	-	-
	Condenser,	-	-	-	-
	Inter-and-After Coolers,	-	-	-	-
	Coolers, Cold Boxes	-	-	-	-
	Expander	-	-	-	-
317.8	Misc. MHD Top Cycle Equip.				
	MHD Cooling Loop & Pump	1.4	-	-	-
	Other Mechanical	2.4	-	-	-
	Piping	0.9	-	-	-
350.1	Main Transformers	3.8	3.7	1.9	3.8
350.2	Switchyard	12.1	11.4	6.1	12.1
	Subtotal Direct Cost	576.0	529.9	289.0	273.9
	Indirect Cost	55.0	54.1		
	Total Field Cost	631.0	584.0		
	Contingency	101.8	86.7		
	Subtotal	732.8	670.7		
	A/E Eng'n Services	59.7	55.8		
	Total Overnight Const. Cost	792.5	726.5		

Table 3A

NOTES TO ACCOMPANY
MHD/PCF PLANT
COST COMPARISON TABLE

The following notes should be read along with the line items in Table 3, identified by the account number.

Acct. No.	
310	Land costs are site specific. Overall cost impact is expected to be small. MHD plant land is costed on the same unit cost basis as the PCF plant.
311.1	Improvements to site and earthwork costs are quite site specific. The $18.3 million allowance has the same basis as the PCF plant. Foundation piles are site specific and required at the PCF plant site. The MHD plant does not have a specific site, and piles are assumed not to be required.
311.22	MHD steam generator foundation costs only are in this account. These are comparable to the 2 x 500 MWe PCF foundations. The PCF account includes cost of structures. MHD structure costs are in Account 312.3-4.
311.23	MHD does not require a flue gas desulfurization (FGD) system, and the associated structures.
312.12	For the MHD only, drier pulverizers, separation cyclones, baghouse filters, petrocarb injection system, and the coal transport-nitrogen compressor are included.
312.4	PCF steam generator scope includes coal pulverizers, air preheaters, and fans, which are not in MHD account. The MHD account includes structures and oxidant heater, which are not in the PCF account.

Table 3A (cont'd)

312.5	MHD electrostatic precipitator (ESP) operates at about 550F versus 280F for PCF ESP. Corresponding air flows are 1,920,000 ACFM versus 2,188,000. The two ESPs have different designs, and the costs are not comparable. The cost for the MHD plant ESP has been provided by Babcock & Wilcox.
	MHD does not require an FGD system, as does the PCF plant.
317.8	Miscellaneous MHD topping cycle equipment includes a channel cooling loop with heat exchangers, pumps, and piping.

. Activity 3 - Operating and Maintenance Cost Analysis

O&M costs are presented in Table 4 along with staffing estimates on Tables 5 and 6. Costs and staffing for both the MHD and PCF plants are given. All costs are at the mid-1978 price level. Total operating costs include fixed O&M costs and variable O&M costs.

As listed in Table 4, fixed O&M costs include plant operating labor, maintenance material and labor, and administrative and support labor. The average labor cost is $29,000 per year for operations and $25,000 per year for maintenance. Annual maintenance costs for the MHD portion of the plant, Account 317, and also the steam generator and electrostatic precipitator, are from the Task II report by General Electric. Annual maintenance costs for the balance of plant (BOP) are estimated using EPRI guidelines as 1.5% of the total overnight construction cost. The cost split between maintenance material and labor is assumed to be 60% and 40%, respectively. Administrative and other support labor is estimated as 30% of the O&M labor. Property taxes and insurance and general and administrative expenses are not included in fixed O&M but rather in the fixed charge rate.

Variable O&M costs, listed in Table 4, include:

- Variable maintenance costs @ one mill per kilowatt hour
- Process water @ $0.37 per 1000 gallons
- Consumables (from GE for the MHD portions)
  - Helium @ $2 per liter
  - Lime @ $30 per ton
  - Coke @ $27 per ton
  - K_2SO_4 @ $160 per ton

  For the BOP portion of the MHD plant and for the PCF plant, general plant chemicals @ $100,000 per month.
- Disposal of solid waste @ $5.40 per ton

Steam and electricity for plant use are not included as direct costs in variable O&M costs, but rather as impacts on the plant heat rate. Disposal of solid waste materials to dedicated waste disposal areas in the plant includes preparation of the area, transport, spreading, dewatering, compaction, and 30 inches of seeded topsoil cover.

Table 5 presents estimated staffing for operations of the MHD and the PCF plant. Estimates were developed from previous studies of plants containing similar operating systems. The staffing estimate assumes a highly instrumented,

computerized operation with adequate sparing of equipment to ensure reasonable reliability of operation as provided in the capital cost estimate. In general, one operator per operating facility with a shift supervisor and central control room operator are estimated for each shift. A total of 4.2 operators are required per specific function for continuous coverage of three-eight hour shifts, seven days per week. Expected illness, vacation, holidays, training and turnover allowances raise this 4.2 figure to 5. The operating staff totals 163 persons for the MHD plant and 135 persons for the PCF Plant.

Table 6 presents the estimated staffing for maintenance of the MHD and the PCF plants. The estimates are based on maintenance as a percent of capital costs for the PCF plant and the BOP facilities of the MHD plant. The estimate for the MHD portion of the plant is based on the maintenance cost data developed by GE in Task II of the study. Maintenance staff totals 210 persons for the MHD plant and 172 persons for the PCF plant.

COST OF ELECTRICITY

Estimated cost of electricity (COE) and other related data are presented in Table 7. First year, 1978, and 30 year levelized COE at the plant leaving the switchyard are given for both the MHD plant and the PCF plant. The capital fixed charge rate used is 18% and the levelizing factor used for both fuel and O&M costs is 2.004. These economic assumptions were provided by NASA.

Efficiencies and heat rates for the MHD and PCF plants are those from the Task II and the EPRI reports respectively. The 65% capacity factor (CF) was specified by NASA for the MHD plant. The same CF has been used for the PCF plant.

For the MHD plant the total capital cost is the bottom line from Table 1. For the PCF plant, the total capital cost, $774.8 million, was computed from the $726.5 million from Table 2 through two adjustments to provide comparability to the MHD. The first adjustment deducts $25.1 million for the site specific earthwork(direct cost $9.9 million) piles and caissons (direct cost $10.3 million) and associated contingency and associated A/E costs not required at the Middletown site. A second adjustment is the addition of $73.4 million for ICD&E using the same interest and escalation rates as used for the MHD and assuming a 6 year project duration.

Table 4

FIRST YEAR OPERATIONS & MAINTENANCE COSTS
(Mid-1978 $ Millions)

	MHD Plant 1x1100 MWe	PCF Plant 2x500 MWe
Fixed O&M Costs		
Plant Operating Labor Costs	$ 4.7	$ 3.9
PCF/MHD BOP Maintenance Labor	2.0	4.3
PCF/MHD BOP Maintenance Material	3.0	6.5
MHD Portion Maintenance Labor	3.1	-
MHD Portion Maintenance Material	10.6	-
Admin. & Support Labor	2.9	2.5
TOTAL FIXED O&M COSTS	$26.3	$17.2
Variable O&M Costs		
Variable Maintenance	$ 6.2	$ 5.7
Process Water	0.7	1.7
Chemicals		
Lime	1.3	1.0
Helium	0.1	-
Coke	0.8	-
K_2SO_4	3.5	-
General Plant Chemicals	1.0	1.6
Disposal of Waste	2.1	2.1
TOTAL VARIABLE O&M COSTS	$15.7	$12.1

Table 5

OPERATIONS STAFFING ESTIMATE

Positions	MHD Plant 1x1100 MWe	PCF Plant 2x500 MWe
Plant Manager	1	1
Office Supervisor	1	1
Secretary	1	1
Clerk Steno	1	1
Clerk Typist	2	2
Supt. of Operations	1	1
Shift Supervisors	5	5
Asst. Shift Supervisors	5	5
Fuel Supply Supervisor	1	1
Technical Supervisor	1	1
Plant Chemist	1	1
Asst. Plant Chemist	1	1
Lab Technicians	2	2
Control & Test Engineer	1	1
Mechanical Engineer	1	1
Electrical Engineer	1	1
Control & Inst. Technicians	8	8
Control & Inst. Trainees	5	5
Control Operators	7	9
Assistant Control Operator	7	9
Auxiliary Operators	21	28
Operator Trainees	5	5
Waste Disposal Operators	13	17
Helper Operators	10	10
Fuelman	16	18
MHD Systems Operators	45	-
Total Operating Staff	163	135

Table 6

MAINTENANCE STAFFING ESTIMATE

Positions	MHD Plant 1x1100 MWE	PCF Plant 2x500 MWE
Supt. of Maintenance	1	1
Maint. Engr. Supervisor	1	1
Maint. Services Supervisor	1	1
Materials Supervisor	1	1
Maintenance Planner	2	2
Maintenance Scheduler	1	1
Maintenance Engineers	3	3
Warehouseman	1	1
Warehouseman Helpers	2	2
Shift Foreman	5	5
Shift Foreman Assistants	5	5
Mechanics	10	10
Instrument Technicians	5	5
Millwrights	10	10
Pipefitters	10	10
Welders	5	5
Electricians	5	5
Mason Insulators	5	5
Painters	3	3
Sheet Metal Workers	3	3
Laborers	20	20
Journeyman Trainees	20	20
MHD Systems Maintenance	38	-
Plant Maintenance Staff	157	119
Contract Maintenance	53	53
Total Maintenance Persons	210	172

Table 7

COST OF ELECTRICITY
FOR MHD & PCF PLANTS
(Mid-1978 Prices)

	1X1100 MWe MHD Plant		2X500 MWe PCF Plant	
Plant Efficiency, %	42.66		33.90	
Plant Heat Rate, Btu/kWh	8,000		10,029	
Power Output, MWe (Net)	1,089.78		1,000	
Annual Generation @65% CF, kWh x 10^9	6.205		5.694	
Total Capital Costs Including IDC&E, $\$10^6$	866.4		774.8	
Unit Capital Costs, $/kWe	795.0		774.8	
First Year Costs, $\$10^6$				
Capital Fixed Charges @18%	$156.0		$139.5	
Fixed O&M Costs	26.3		17.2	
Variable O&M Costs	15.7		12.1	
Fuel Costs @ $\$1.05/10^6$ Btu	52.1		60.0	
Total Costs	$250.1		$228.8	
	First Year 1978	30 Year Lev.*	First Year 1978	30 Year Lev.*
Mills/kWh				
Capital Fixed Charges	25.1	25.1	24.5	24.5
Fixed O&M Costs	4.2	8.4	3.0	6.0
Variable O&M Costs	2.5	5.0	2.1	4.3
Fuel (Coal) Cost	8.4	16.8	10.5	21.1
Total	40.2	55.3	40.1	55.9

* Levelizing Factor = 2.004

APPENDIX A
NASA CODE OF ACCOUNTS SCOPE LIST

NASA CODE OF ACCOUNTS SCOPE LIST

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
310.00 LAND AND LAND RIGHTS	Land area requirements	This account includes the cost of all land purchase and costs associated with the purchase of land for the project site.
311.00 STRUCTURES AND IMPROVEMENTS		This account includes the cost of all buildings and structures on the site, including yard facilities. Foundations for equipment within the buildings are costed with the structures due to the difficulty in separating foundations from the building structure. All building services, including cranes, are included in the building costs. Foundations for equipment outside the buildings are either costed with the equipment or identified separately, depending upon the related historical data base.
311.1 Improvements to Site	Soil investigation and preparation Groundwater control Dredging Major earthfill structures Open channels, canal, and ditches	

NASA CODE OF ACCOUNTS SCOPE LIST

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
311.1 Improvements to Site (cont'd.)	Tunneling Cut and fill, right-of-way earthwork Miscellaneous earthwork Marine facilities Finish grading and surface treatment Fences, railings and gateways Major composite structures (i.e. bridges) Railroads and miscellaneous trackage Roads, walks and parking areas Manholes and catchbasins Culverts and flopgates Storm and open drain yard piping Miscellaneous site improvements	
311.2 Main Buildings & Structures		All items listed from 311.2 through 311.6 in the "Items Included" column are costed for each building listed from 311.2 through 311.6 unless not applicable
311.21 MHD Building 311.22 Steam Generator 311.23 Effluent Control 311.24 Inverter Building 311.25 Control Building	Concrete Category Temporary formwork Permanent forms Reinforcing steel Embedded metal	 Structure in 312.4 account Structure in 312.5 account
311.3 Steam Turbine Generator Building	Structural concrete Mudmats/fill concrete tremie concrete Waterproofing and joint treatment	
311.4 Coal Bunker/Processing Area	Prestressing	
311.41 Thaw, Soak and Car Unloading Buildings	Precast structural components	

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
311.4 Coal Bunker/Processing Area (Cont'd)		
	Steelwork, Architectural and Civil Category	
311.42 Scale House	Structural steel	
311.43 Sample Station	Miscellaneous iron and steel	
311.44 Alternate Coal Feed Structure	Misc. fabricated commodities	
	Architectural features and finish	
311.45 Coal Prep. and Feed Building	Earthwork, dredging and finish	
311.46 Transfer Stations	Structure excavation and backfill	
311.47 Live Storage		
311.481 Conveyor Gallery	Piles and caissons	Piles and caissons are not required at Middletown site.
311.482 Bents	Bearing piling	
	Sheeting and shoring	
	Caissons	
	Foundation grouting	
311.5 Service Buildings	Cofferdams	
	Permanent sheet piling	
311.51 Service Building	Floor and equipment drains piping	
311.52 Administration Bldg		
311.53 Guard Houses	Misc. civil/structural/ architectural	The miscellaneous account is reserved for widely subcontracted buildings and structures or other exceptional facilities which cannot be properly charged to other established accounts
311.6 Other Process Buildings and Structures	Cranes and hoists	
	Elevators	
	Building fire protection	
311.611 Air Compression Bldg	Plumbing & sanitary equip.	
311.612 Air Separation Bldg	Heating/ventilation, air conditioning equip.	
311.613 Oxygen Compression Building	Lighting	
311.614 Nitrogen Compression Units	Nonprocess, indoor building services piping	
311.62 Circulating Water Pump House		
311.63 Water Treatment Bldg		
311.64 Fuel Oil Storage		
311.65 River Intake Structure		

NASA CODE OF ACCOUNTS SCOPE LIST

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
311.6 Other Process Building and Structures (Cont'd.)		
311.66 Seed Reprocess and Storage Bldg.		
311.67 Seed Injection Structure		
311.68 Cooling Tower Basin		Structure in 314.32
311.69 Inverter Area		Structure in 317.4
312.00 BOILER PLANT EQUIPMENT		In addition to equipment, costs here include associated piping, instrumentation and related electrical equipment furnished with equipment
312.1 Coal Handling and Processing	Coal unloading equipment Coal preparation equipment Coal handling equipment Coal dust suppression equipment Coal conditioning equipment Local panelboards Field-mounted instruments Insulation	Includes all equipment from initial unloading point up to and including coal storage prior to final preparation. Final preparation, which includes drying and pulverizing, is costed in account 317.1
312.2 Slag and Ash Handling	Ash handling equipment Bottom ash pumps and drives Fly ash fans and blowers Fly ash silos and unloaders Bottom ash bins/tanks Insulation Piping Local Panelboards	Includes all equipment from the initial collection up to the storage area.

NASA CODE OF ACCOUNTS SCOPE LIST

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
312.2 Slag and Ash Handling (cont'd)		
	Field-mounted instruments Control and relief valves	
312.3 Radiant Section (included with 312.4)		
312.4 Main Steam Generator	Main steam generator Forced draft fans and drives Piping Insulation Control and relief valves	Includes radiant section, superheat reheater, economizer, oxidant heater As included with vendor supplied steam generator
	Structures	Foundations in 311.22
312.5 Effluent Control		Includes all equipment from the steam generator outlet up to and including the chimney
	Electrostatic precipitators/bag-houses Stacks and accessories Induced draft fans and drives	

NASA CODE OF ACCOUNTS SCOPE LIST

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
312.5 Effluent Control (cont'd)		
	Gas recirculation fans and drives	
	Piping	
	Local panelboards	
	Field-mounted instruments	
	Insulation	
	Control and relief valves	
	Structures	Foundations in 311.23
312.6 Auxiliary Boiler Systems	Auxiliary boiler	
	Auxiliary boiler pumps and drives	
	Auxiliary boiler tanks & vessels	
	Piping	
	Local panelboards	
	Field-mounted instruments	
	Insulation	
	Control and relief valves	
312.7 Other Boiler Plant Systems		
312.71 Condensate System	Condensate pumps and drives	
	Condensate makeup pumps and drives	
	Condensate tanks and vessels	
	Piping	
	Local panelboards	
	Field-mounted instruments	
	Insulation	
	Control and relief valves	
312.72 Boiler Feedwater System	Boiler feedwater pumps and drives	
	Boiler feedwater heat exchangers	
	Piping	
	Local panelboards	
	Field-mounted instruments	

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
312.7 Other Boiler Plant Systems (Cont'd)		
312.73 Boiler Plant Water Treatment	Demineralizers Condensate Polishers Chemical feed equipment Piping Local panelboards Field-mounted instruments Insulation Control and relief valves	
312.74 Miscellaneous Boiler Plant Equipment	Soot blower air compressors and auxiliaries	
313.00 ENGINES AND ENGINE DRIVEN GENERATORS		Not applicable to this design
314.00 TURBOGENERATOR UNITS		This account includes the bottoming cycle equipment associated with steam turbine generator power generation.
314.1 Steam Turbine Generator and Auxiliaries	Turbine generator Turbine generator insulation/lagging Local panelboards Field-mounted instruments Piping Insulation Control and relief valves	
314.2 Condenser and Auxiliaries	Main condenser and auxiliaries Air removal equipment Main condenser insulation/lagging Local panelboards	

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
314.2 Condenser and Auxiliaries (cont'd)	Field-mounted instruments Piping Insulation Control and relief valves	
314.31 Circulating Water System	Circulating water pumps and drives Circulating water heat exchangers Circulating water tanks Piping Local panelboards Field-mounted instruments Insulation Control and relief valves	
314.32 Cooling Towers	Main cooling towers Piping Local panelboards Field-mounted instruments Insulation Control and relief valves	Basin and foundations in 311.68 Includes piping, valves, instrumentation provided by cooling tower vendor
314.4 Steam Piping Systems	Piping, including hangers, insulation, testing and control and relief valves	Includes main steam, hot and cold reheat steam, extraction steam, bypass steam system.
314.5 Other Turbine Plant Equipment	Main lube oil system	
315.00 ACCESSORY ELECTRIC SYSTEMS AND EQUIPMENT		This account contains the cost of equipment to supply station auxiliary power and the inplant equipment associated with the power generation. Also included in this account is the station control equipment with the associated computer. The power conditioning equipment is included in Account 317 and the substation/switchyard equipment is costed in Account 350.

NASA CODE OF ACCOUNTS SCOPE LIST

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
315.00 Accessory Electric Systems and Equipment (Cont'd.)		
Station Auxiliary Power System	Switchgear and load-center units Transformers D.C. Equipment and motor generator sets Wires, cable and conduit Bus ducts and supports Miscellaneous equipment	
Emergency Power System	Switchgear and load-center units Transformers Wire, cable and conduit Miscellaneous equipment	
Control System (includes Data Acquisition)	Instrument piping/tubing insulation Main control room panelboards Plant computer and auxiliaries Control system packages Miscellaneous materials and special operations Remote motor controls and distribution panels Communication and plant protection equipment Miscellaneous equipment	
316.00 MISCELLANEOUS POWER PLANT EQUIPMENT		Includes all equipment and subsystems not otherwise identified.
Plant Fire Protection System	Yard fire protection supply and hose system Carbon dioxide fire protection equipment	Excludes fire protection systems in buildings

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
316.00 Miscellaneous Power Plant Equipment (cont'd)	Portable fire fighting equipment	
Station Maintenance Equipment	Machine shop cranes and hoists	
	Pipe cleaning and protection	
Fuel Oil System	Building equipment & furniture	
	Fuel oil tanks	
	Fuel oil pumps & drives	
	Fuel oil heat exchangers	
	Fuel oil unloading/fill pumps and drives	
	Fuel oil unloading/fill heat exchangers	
	Insulation	
	Piping	
Raw Water Makeup System	Plant water makeup pumps & drives	
	Screenwell equipment	
	Service/circulation water chemical injection	
	Raw water purification/ filtration equipment	
	Piping	
	Insulation	
	Control and relief valves	
	Field-mounted instruments	
Service Water System	Service water pumps/drives	
	Service water heat exchangers	
	Piping	
	Insulation	
	Control and relief valves	
	Field-mounted instruments	

NASA CODE OF ACCOUNTS SCOPE LIST

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
316.00 Miscellaneous Power Plant Equipment (cont'd.)		
Miscellaneous equipment	Miscellaneous pumps and drives Miscellaneous heat exchangers Miscellaneous tanks and vessels Miscellaneous piping Insulation	
317.00 <u>MHD TOPPING CYCLE EQUIPMENT</u>		This account includes all topping cycle equipment
317.1 Combustion Equipment	Primary gasifiers Slag receivers Second stage combustor Slag quench tank Ducts Coal/oil injectors Expansion joints Electrical isolation Seed injector Piping Insulation Relief and control valves Local panelboards Field-mounted instruments	
317.2 MHD Generator System	Nozzle MHD generator Diffuser Channel Installation Piping Local panelboards Field-mounted instruments Insulation Control and relief valves	

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
317.3 Magnet System	Magnet	
	Cryogenic subsystem	
	Miscellaneous materials	
	Piping	Only in cryogenic subsystem
	Insulation	
	Local panelboards	
	Field-mounted instruments	
	Control and relief valves	
317.4 Inverters and Electrode Control System	Inverter valve modules	
	Current consolidation equipment	
	Direct current reactors	
	Alternating current filters and power correction equipment	
	Transformers	
	Switchgear includes D.C. breakers	
	Instrument and control	
317.5 Oxidizer System	Main oxygen compressor and drive turbine	
	Condenser for drive turbine	
	Intercooler and aftercoolers	
	Piping	
	Insulation	
	Local panelboards	
	Field-mounted instruments	
	Control and relief valves	
317.6 Seed System	Seed handling and storage equip.	
	Formate plant	
	Seed injection equipment	
	Piping	
	Insulation	
	Local panelboards	
	Field-mounted instruments	
	Control and relief valves	

NASA CODE OF ACCOUNTS SCOPE LIST

CODE OF ACCOUNTS	ITEMS INCLUDED	REMARKS
317.7 Oxygen Enrichment System	Air compressors and drive turbine Condenser for drive turbine Inter- and after-coolers Cold boxes Expanders Piping Insulation Local panelboards Field-mounted instruments Control and relief valves	
317.8 Miscellaneous MHD Topping Cycle Support Equipment	MHD cooling loop heat exchangers MHD cooling loop pumps Miscellaneous mechanical equipment Piping Insulation Local panelboards Field-mounted instruments Control and relief valves	
350.00 <u>TRANSMISSION PLANT</u>	Main power transformers Circuit breakers Switchgear Insulators/conductors Surge protection equipment Wire and cable Miscellaneous switchyard equipment and materials Switchyard related structures and foundations	This account includes the cost of all the switchyard equipment downstream of and including the main power transformer.

APPENDIX B

IMPACT OF REDUCTION OF OXYGEN ENRICHMENT LEVEL

EFFECTS OF REDUCING OXYGEN ENRICHMENT LEVELS FROM 37.6% (VOL) to 30% (VOL)

INTRODUCTION - The GE PSPEC Task II MHD cycle design specified the oxygen enrichment level to be 37.6% by volume. This level was chosen to optimize the performance of the MHD combustor and channel. Lower oxygen enrichment levels will slightly reduce the MHD performance but may offer significant savings in the cost of the air separation un. (ASU). The information developed in this appendix analyzes the cost - performance trade-off of a reduction of the design point oxygen enrichment level (37.6%) to a lower level chosen at 30%.

OPERATING PARAMETERS - A reduction in oxygen enrichment level modifies the oxidant and combustion gas flow parameters (flow rate, pressure and temperature) throughout the cycle. A listing of the major changes is contained in Table B-1. The ASU plant oxygen production is reduced by about 30% from 10174 tons per day (TPD) of contained O_2 to 6865 TPD. Since the cost of the ASU Plant is a direct function of the TPD of contained oxygen, a substantial cost reduction is possible. The reduced O_2 level is reflected in combustor performance by a reduced flame temperature. This in turn reduces the pressure ratio over which the channel operates. Table B-1 indicates that the channel pressure will drop from 10.0 ATM to 7.1 ATM. This reduction produces a potential savings in the cycle compressor power requirement. In this analysis the amount of coal being combusted was held constant. In order to maintain the maximum possible firing temperature the flow of the 30% enriched oxidant was increased from 417 Kg/sec to 512 Kg/sec by increasing the amount of air mixed with the ASU product stream. This increased flow offsets the reduction in cycle compressor power made possible by the pressure reduction noted above. The combination of the pressure reduction and the higher mass flow rate greatly increases the volumetric flow of the oxidant and combustion gas. In order for the MHD nozzle to maintain the aerodynamic conditions (Mach No) at the channel inlet the physical dimensions of the channel and, hence, the magnet, will have to increase. This size increase has a significant effect on channel and magnet cost. Finally, the combustion gas properties in the channel have the effect of reducing the amount of enthalpy extraction from 24.75% to 22.82%. The lower channel DC output is offset by an increase in thermal energy available to the heat recovery equipment and a concurrent rise in steam turbine power output.

PERFORMANCE EFFECTS - The impact on performance of the reduction in oxygen enrichment level is illustrated by Figure B-1. This data, taken from NASA computer runs, indicate that at the channel length in this analysis, 22 meters, the reduction of oxygen enrichment level has no significant impact on plant thermal efficiency. With the coal consumption rate and cycle efficiency held constant, the fuel portion of the cost of electricity will also be constant.

COST ANALYSIS - Changes in the cycle operating parameters are reflected directly in the cost of the cycle components. The costs of the components were scaled (both upwards and downwards) to the 30% O_2 level utilizing the assumptions in Table B-2. The capital cost effects of this scaling are contained in Table B-3. Table B-3 indicates that the ASU and magnet costs experience the greatest change and that the reduction in ASU cost is more than offset by an increase in the magnet cost. The basis of these two cost estimates is explained in detail below. Other component costs vary slightly, both up and down, with little overall impact on the total costs. The end result is a net cost increase in capital cost of approximately 2 million dollars or approximately .33% of the total capital cost of the plant.

- ASU Costs - In the GE PSPEC Task II Conceptual Design Study, the total oxidant flow was determined to be 417.3 KG/sec (39, 750 TPD) at the 37.6% (vol) oxygen level. At the 30% O_2 level the required oxidant flow, as calculated by the NASA chemical equilibrium computer code was determined to be 511.9 Kg/sec (48,762 TPD). The capacities of the two ASU plants required to produce these oxidant flows can then be determined from the following expression:

$$\text{ASU capacity} = E\ \sigma \left(\frac{e - a}{\sigma - a}\right)$$

where: E = oxidant mass flow (TPD)

e = oxygen mass fraction in oxidant flow

a = oxygen mass fraction in dry air (.23144)

σ = oxygen mass fraction in ASU product (.71849)

The ASU capacity for each of the two cases is then calculated to be:

Oxidant O_2 %(Vol)	ASU Capacity (TPD)
37.6	10,174
30.0	6,865

In order to maintain component sizes within reasonable, transportable limits, ASU plants are generally limited to capacities below 5000 TPD with parallel trains being used to achieve the total required capacity. For this reason, and for comparative purposes, the ASU plant for the 37.6% O_2 case is assumed to consist of 3 parallel trains of approximately 3400 TPD each and the 30% O_2 ASU plant to consist of 2 parallel trains of approximately 3400 TPD each. The capital cost of air separation units of different capacities was obtained from data supplied by NASA and illustrated in Figure B-2. The specific cost of a single parallel train in each of two plants as derived from Figure B-2 is $8600\frac{\$}{TPD}$. Calculating the total cost by multiplying the specific cost by the ASU capacity is found to be:

Oxidant O_2% (Vol)	Total Capital Cost($\$ x10^{-6}$)
37.6	87.5
30.0	59.0

These results indicate that a capital cost savings of almost 30 million dollars can be achieved by reducing the oxygen content from 37.6%(vol) to 30%(vol).

- Magnet Costs - The cost of the magnet for the 37.6% O_2 case is \$77,300,000 as noted in Table 1 in the main body of this report. A detailed description of the cost estimate is given in the GE PSPEC Task II report in Section 3.4. The cost can be scaled to the 30% O_2 case by utilizing the cost estimating curve from the MIT National Magnet Laboratory illustrated in Figure B-3. Note that for magnets of the size being considered in this study ($VB^2 > 500$) the cost curve approaches a straight line and can be represented by the expression:

$$\text{Magnet Cost} = (VB^2)^{.7}$$

In this equation the volume parameter (V) is a characteristic volume calculated by multiplying the magnet warm bore inlet area(A_{WB}) by the magnet active length(L_a). The active length is taken as the distance along the channel axis from the point where the inlet field is 80% of maximum field strength (.8B) to the point where the exit field is 80% of the exit crest (.8Bc). Hence,

$$\text{Magnet Cost} = (A_{WB} \times L_a \times B^2)^{.7}$$

The ratio of the magnet costs for two systems of different size can be expressed as:

$$\frac{\text{Magnet Cost @ 30\% } O_2}{\text{Magnet Cost @ 37.6\% } O_2} = \frac{\left(A_{WB} \times La \times B^2\right)^{.7}_{30\%}}{\left(A_{WB} \times La \times B^2\right)^{.7}_{37.6\%}}$$

Assuming the magnet active length and field strength are the same for each case;

$$\frac{\text{Magnet Cost @ 30\% } O_2}{\text{Magnet Cost @ 37\% } O_2} = \left(\frac{A_{WB\ 30\%}}{A_{WB\ 37.6\%}}\right)^{.7}$$

Since the magnet must encompass the channel, the warm bore inlet area is dependent on the channel cross section dimensions. The ratio of warm bore inlet area to channel area (AC) is 3.52 and 3.23 for the 37.6% O_2 case and 30% O_2 case respectively. Hence,

$$\frac{\text{Magnet Cost @ 30\% } O_2}{\text{Magnet Cost @ 37.6\% } O_2} = \left(\frac{3.23 \quad Ac_{\ 30\%}}{3.52 \quad Ac_{\ 37.6\%}}\right)^{.7}$$

As noted in Table B-1, a reduction of oxygen content in the oxidant flow reduces the pressure at the channel inlet and increases the total mass flow. The channel, therefore, must be considerably larger to maintain the same aerodynamic conditions (Mach No) through the channel. The flow function which relates channel area (Ac) to Mach Number (M) and flow conditions ($\dot{m}$, P, T) can be expressed as follows

$$A_c = \frac{\dot{m}\sqrt{T}}{P \quad M\sqrt{\frac{g_c \gamma}{R}}}$$

For the two cases being considered, assuming Mach Number (M) and gas properties (γ, R) are constant, the cost ratio can be expressed as:

$$\frac{\text{Magnet Cost @ 30\% } O_2}{\text{Magnet Cost @ 37.6\% } O_2} = \left[\frac{\left(3.23 \dfrac{\dot{m}\sqrt{T}}{P}\right)_{30\%}}{\left(3.52 \dfrac{\dot{m}\sqrt{T}}{P}\right)_{37.6\%}} \right]^{.7}$$

The parameter values at the channel inlet for the two cases are:

	37.6% O_2	30% O_2
$\dot{m}$ (Kg/sec)	537.5	632.1
T (°K)	2842	2676
P (Psia)	147.7	103.8

The ratio of the costs is calculated to be 1.322 and hence:

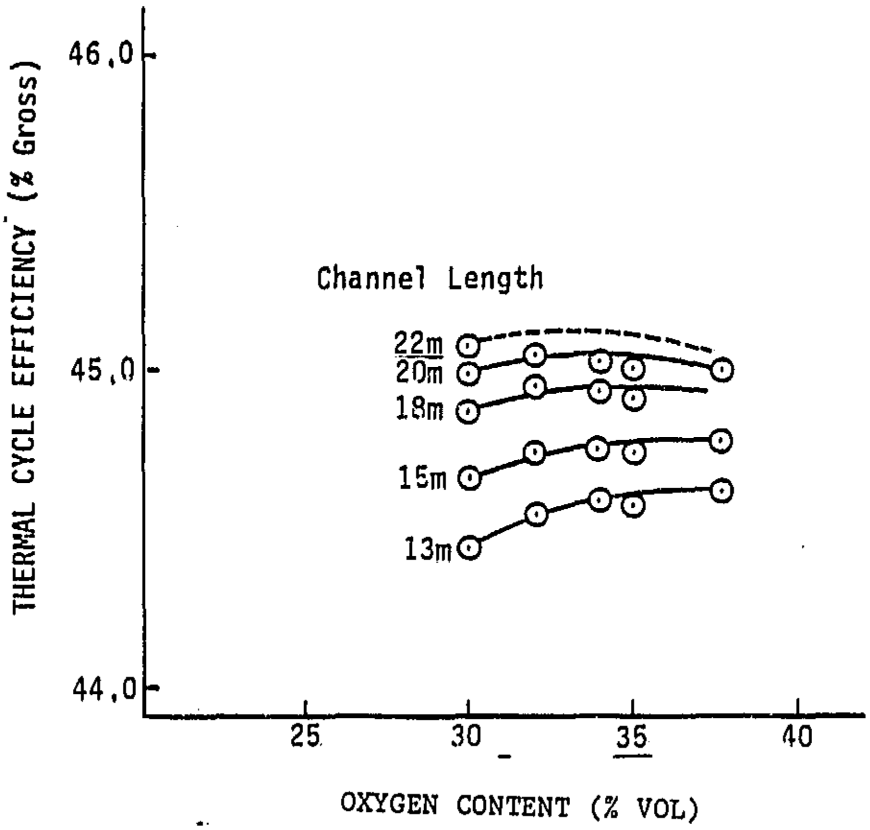
Magnet Cost @ 30% O_2 = 1.322 x \$77,300,000 = \$102, 200,000

- A summary of the capital costs of components affected by the oxygen enrichment level is contained in Table B-3. The bottom line of Table B-3 indicates that cost savings in some components are offset by increases in others, resulting in a net increase of one third of 1%. Since capital costs account for less than half of the cost of electricity (COE) the total effect, as shown on table B-4, is insignificant.

CONCLUSIONS - The results of this analysis indicate that a reduction of oxygen enrichment level has no significant impact on either cycle performance or cost of electricity. The selection of an optimum level of oxygen enrichment will depend on more qualitative criteria such as transportability, constructability, maintainability, durability, etc.

FIGURE B-1

1100 MWE PLANT E. ICIENCY (WITHOUT AUXILIARIES)



CONCLUSION:	REDUCTION OF O_2 ENRICHMENT LEVEL HAS NO SIGNIFICANT IMPACT ON PLANT THERMAL EFFICIENCY FOR 22M CHANNEL

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Figure B-2

Air Separation Unit Costs vs Capacity(Turnkey Cost-70% Purity Plant w/o Compressors and S.T. Drive, ONCC, Mid 1978 $)

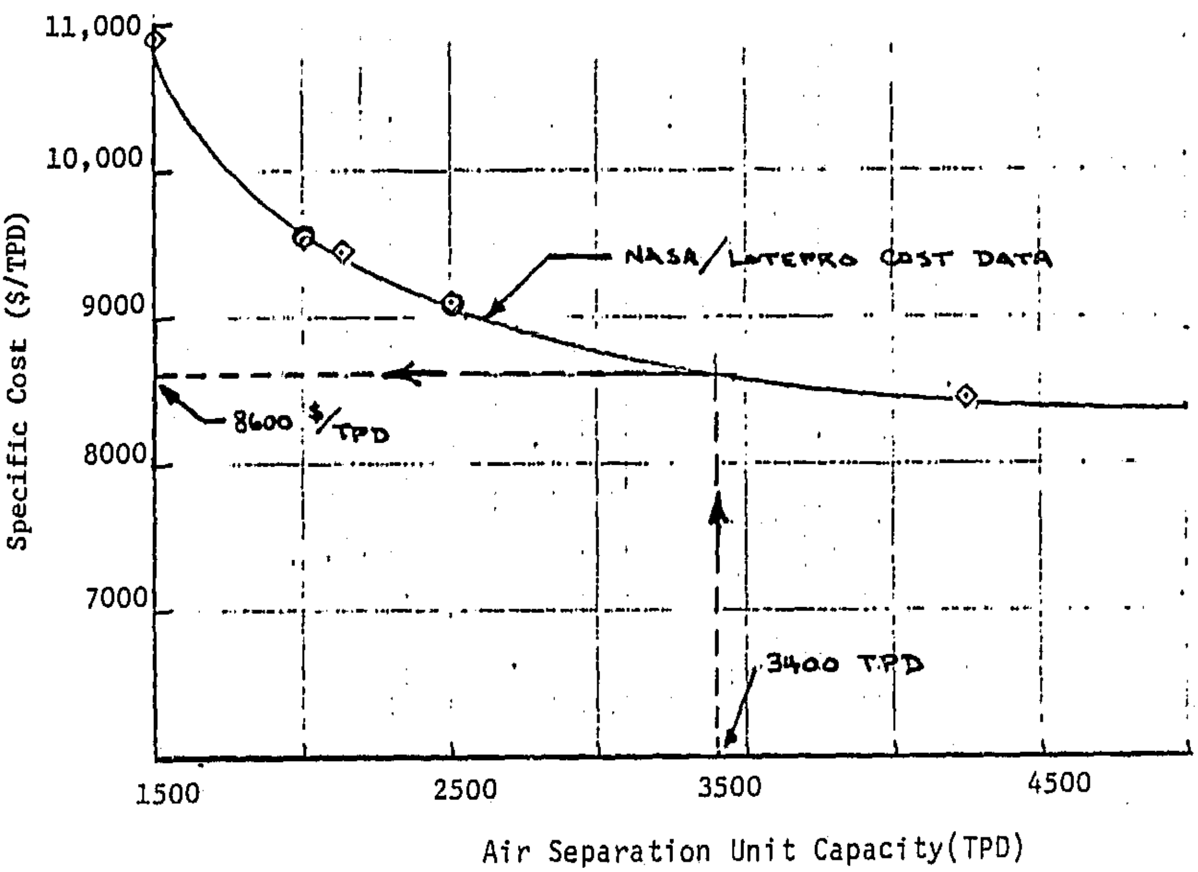

FIGURE B-3

ESTIMATED MAGNET SYSTEM COST
VS.
SIZE FACTOR

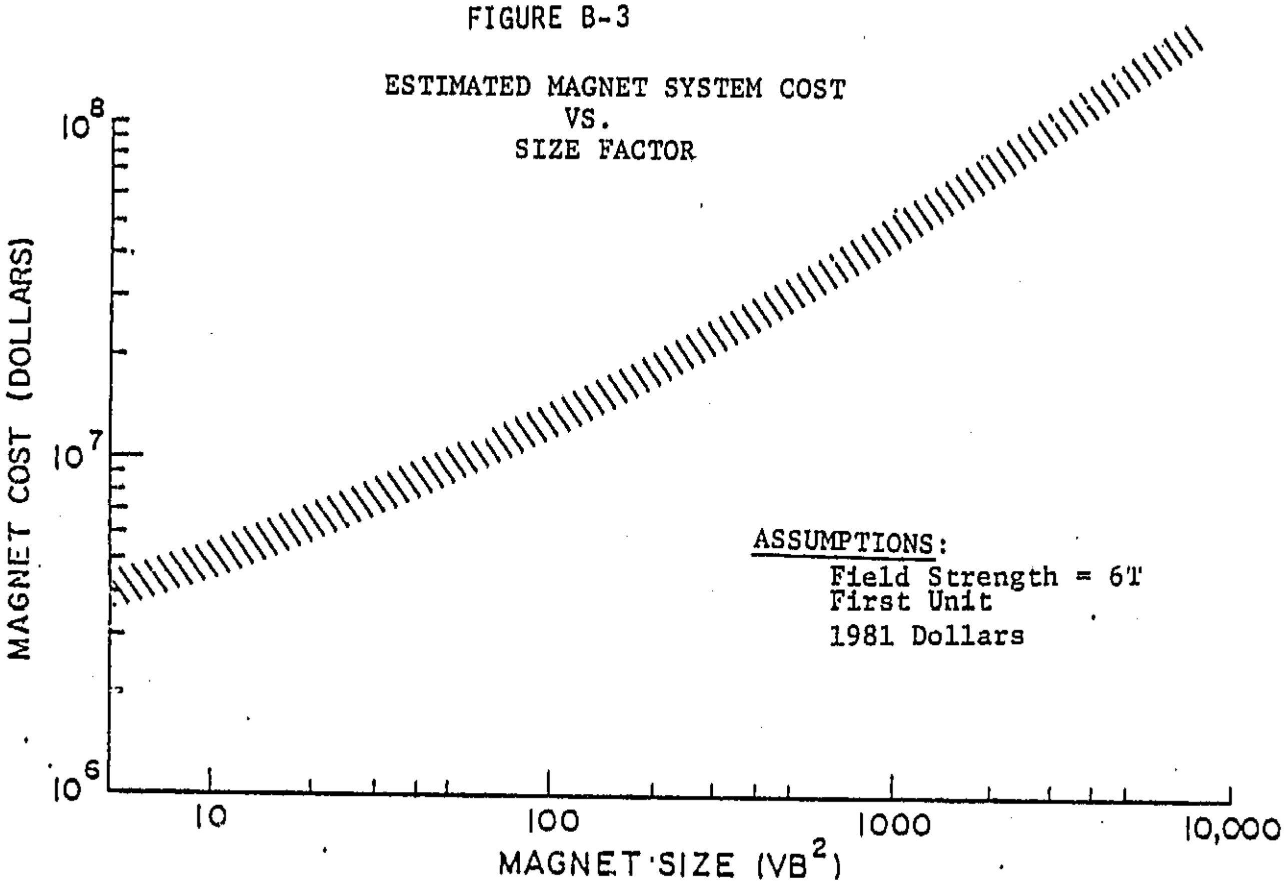

TABLE B-1

OPERATING PARAMETERS	OXYGEN ENRICHMENT (% VOL)		EFFECT OF % O_2 REDUCTION
	37.6%	30%	
ASU PLANT (TPD CONTAINED O_2)	10174	6865	LOWER ASU COST
CHANNEL INLET PRESSURE (ATM)	10.0	7.1	LOWER CYCLE COMPRESS POWER
OXIDANT FLOWRATE (KG/SEC)	417	512	OFFSETS EFFECT OF REDUCED COMBUSTOR PRESSURE HIGHER VOLUMETRIC FLOW LARGER COMBUSTOR, NOZZLE, CHANNEL, MAGNET
CHANNEL ENTHALPY EXTRACTION %	24.75	22.82	LOWER MHD OUTPUT INCREASED STEAM TURBINE OUTPUT

TABLE B-2

ASSUMPTIONS FOR CAPITAL COST ANALYSIS

- TASK III ASU PRODUCES 70% ENRICHED O_2
- MAJOR COMPONENT COSTS SCALED AS FOLLOWS:

COMPONENTS WITH VARIABLE COST	COST SCALING FUNCTION
CHANNEL	SURFACE AREA
MAGNET	BORE DIMENSION, FIELD STRENGTH
	$(VB^2)^{.7}$
INVERTER	$(P_{MHD})^{.7}$
ASU	NASA DATA (FIGURE B-2)
HEAT RECOVERY	SCALED FROM PSPEC CALCULATIONS
ESP	
TURBINE/GENERATOR	$(P_{ST})^{.7}$
CYCLE COMPRESSOR	$(P_C)^{.7}$

TABLE B-3

CAPITAL COST EFFECTS ($K)

COMPONENT	COST @ 37.6% O_2(K$)	COST @ 30% O_2(K$)	COMMENTS
ASU	87,500	59,300	30% LOWER TPD CONTAINED O_2
CHANNEL	15,400	17,700	LARGER CROSS SECTION TO MAINTAIN MACH NO.
INVERTER	59,000	55,700	REDUCTION IN DC POWER
MAGNET	77,300	102,200	LARGER CHANNEL INCREASES WARM BORE VOLUME
HRSR	60,100	60,400	HIGHER GAS FLOW LARGER LMTD
ESP	21,700	24,400	HIGHER GAS FLOW
STEAM TURB/GEN	64,800	69,300	STEAM POWER INCREASE
CYCLE COMP	30,500	29,700	LOWER COMBUSTOR PRESSURE HIGHER OXIDANT FLOW
	416,300	418,700	

% CHANGE IN TOTAL CAPITAL COSTS = $\frac{418{,}700 \quad\quad ,300}{732{,}800} \times 100 = + .33\%$

TABLE B-4

EFFECT ON COE

30 YEAR LEVELIZED COSTS (MILLS/KWH)

	37.6% O_2	30% O_2
CAPITAL	25.1	25.2
O/M	13.4	13.4
FUEL	16.8	16.8
	55.3	55.4

ASSUMPTIONS:

- PLANT EFFICIENCIES ARE THE SAME FOR BOTH CASES, CAUSING THE FUEL PORTION OF COE TO REMAIN CONSTANT
- O/M COSTS ARE THE SAME FOR BOTH CASES

CONCLUSION: REDUCTION OF O_2 ENRICHMENT LEVEL HAS VIRTUALLY NO IMPACT ON COE.